

Network Systems
Science & Advanced
Computing
Biocomplexity Institute
& Initiative
University of Virginia

Estimation of COVID-19 Impact in Virginia

September 9th, 2020

(data current to September 8th)

Biocomplexity Institute Technical report: TR 2020-111



BIOCOMPLEXITY INSTITUTE

biocomplexity.virginia.edu

About Us

- Biocomplexity Institute at the University of Virginia
 - Using big data and simulations to understand massively interactive systems and solve societal problems
- Over 20 years of crafting and analyzing infectious disease models
 - Pandemic response for Influenza, Ebola, Zika, and others



Points of Contact

Bryan Lewis
brylew@virginia.edu

Srini Venkatramanan
srini@virginia.edu

Madhav Marathe
marathe@virginia.edu

Chris Barrett
ChrisBarrett@virginia.edu

Biocomplexity COVID-19 Response Team

Aniruddha Adiga, Abhijin Adiga, Hannah Baek, Chris Barrett, Golda Barrow, Richard Beckman, Parantapa Bhattacharya, Andrei Bura, Jiangzhuo Chen, Clark Cucinell, Patrick Corbett, Allan Dickerman, Stephen Eubank, Arindam Fadikar, Joshua Goldstein, Stefan Hoops, Sallie Keller, Ron Kenyon, Brian Klahn, Gizem Korkmaz, Vicki Lancaster, Bryan Lewis, Dustin Machi, Chunhong Mao, Achla Marathe, Madhav Marathe, Fanchao Meng, Henning Mortveit, Mark Orr, Przemyslaw Porebski, SS Ravi, Erin Raymond, Jose Bayoan Santiago Calderon, James Schlitt, Aaron Schroeder, Stephanie Shipp, Samarth Swarup, Alex Telionis, Srinivasan Venkatramanan, Anil Vullikanti, James Walke, Amanda Wilson, Dawen Xie



Overview

- **Goal:** Understand impact of COVID-19 mitigations in Virginia
- **Approach:**
 - Calibrate explanatory mechanistic model to observed cases
 - Project infections through November
 - Consider a range of possible mitigation effects in "what-if" scenarios
- **Outcomes:**
 - Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
 - Geographic spread over time, case counts, healthcare burdens

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.

Even without perfect projections, we can confidently draw conclusions:

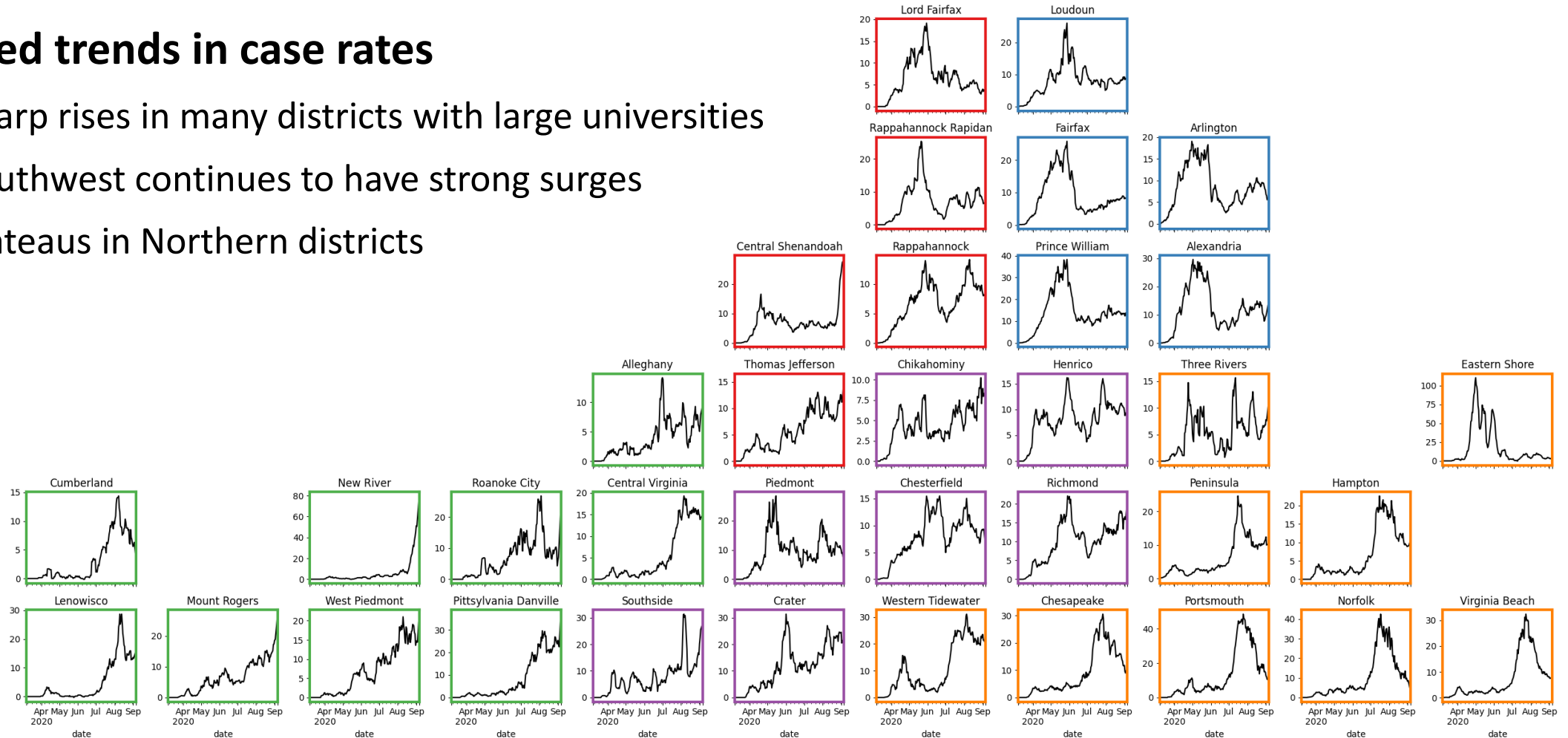
- **Mixed trends remain, with strong surges in several districts.**
- Incidence hovers at national average, which is higher this week ~13/100K.
- Projections are also mixed across a range of slow-growth, plateaus, and declines.
- Recent updates:
 - Adaptive Fitting projection remains, slight adjustments to projection filtering.
 - Trajectory descriptions more fully developed.
- The situation is changing rapidly. Models will be updated regularly.

Situation Assessment

Case Rate (per 100k) by VDH District

Mixed trends in case rates

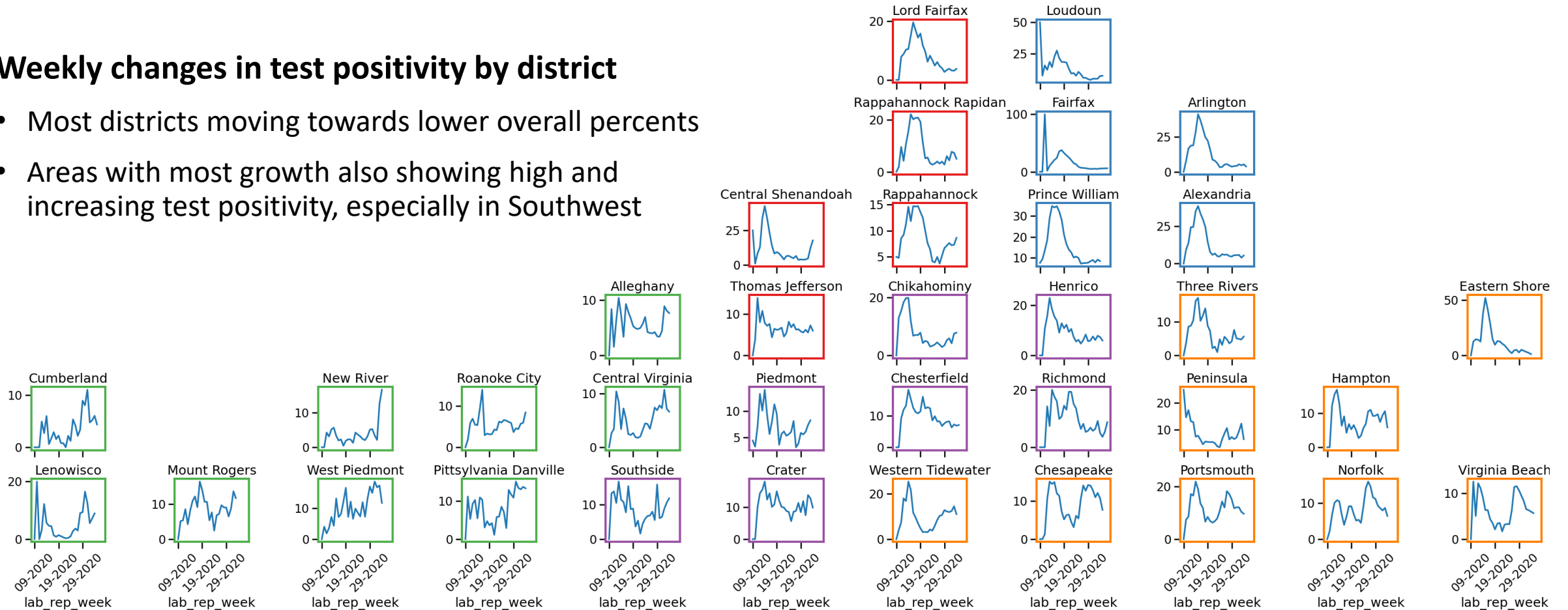
- Sharp rises in many districts with large universities
- Southwest continues to have strong surges
- Plateaus in Northern districts



Test Positivity by VDH District

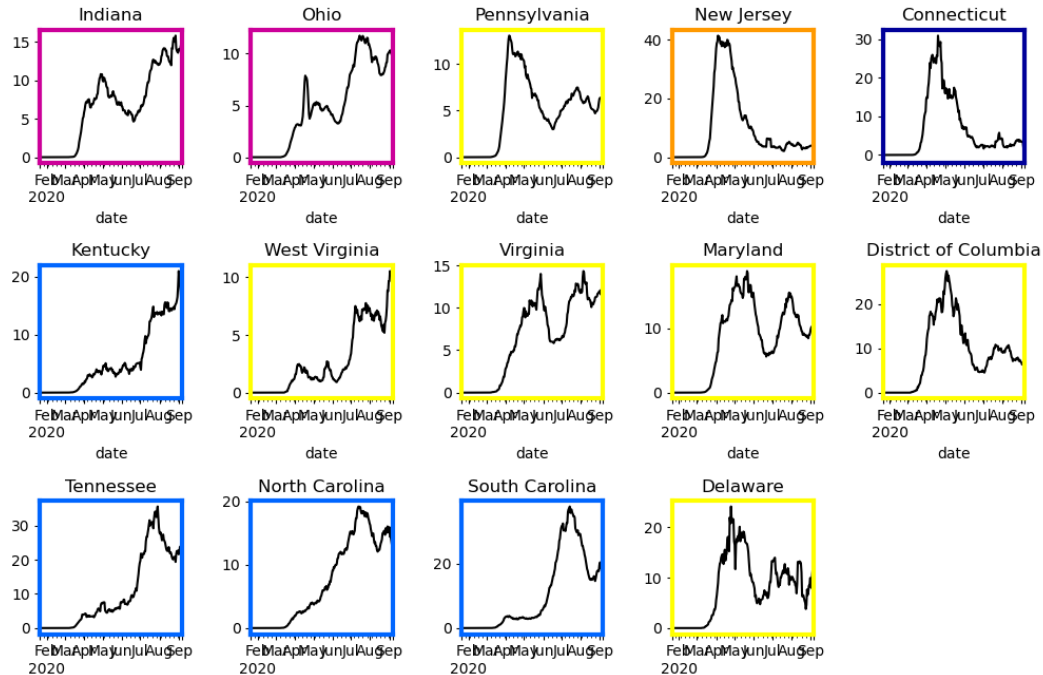
Weekly changes in test positivity by district

- Most districts moving towards lower overall percents
- Areas with most growth also showing high and increasing test positivity, especially in Southwest

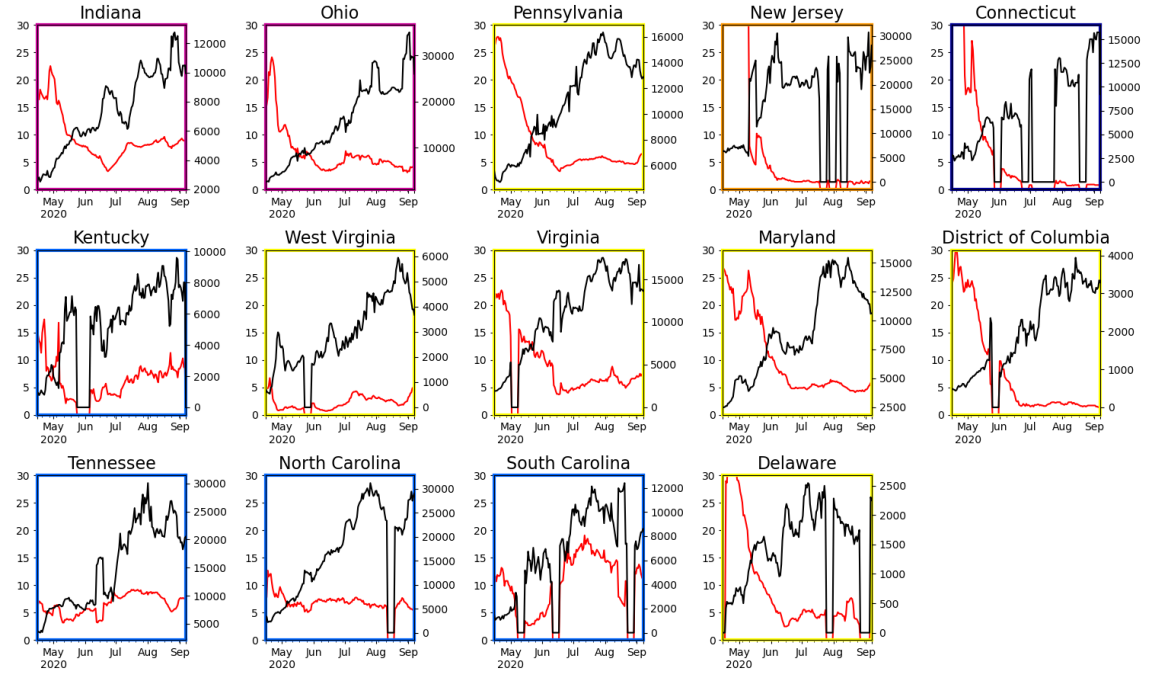


Other State Comparisons

Case Rate per 100K population



Tests per Day and **Test Positivity**



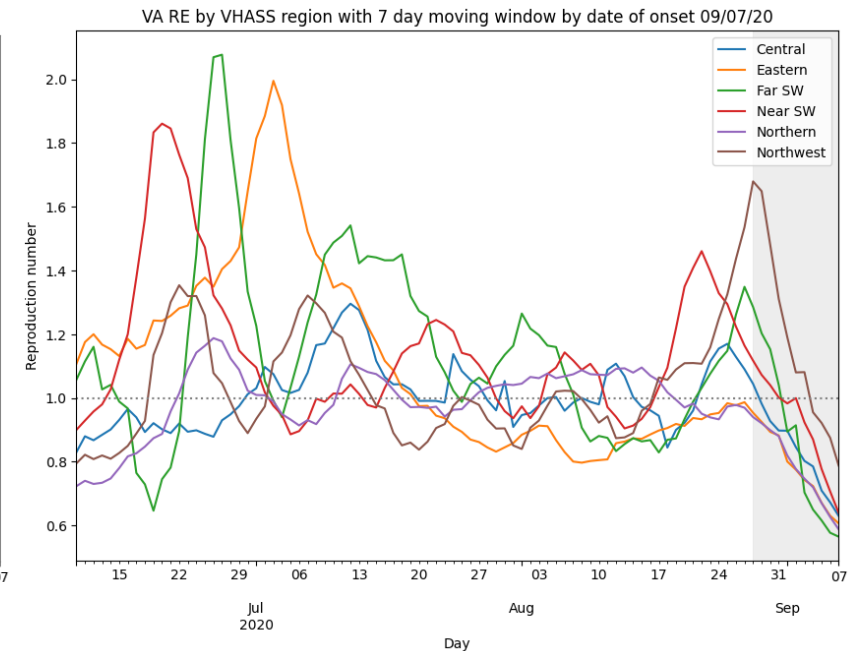
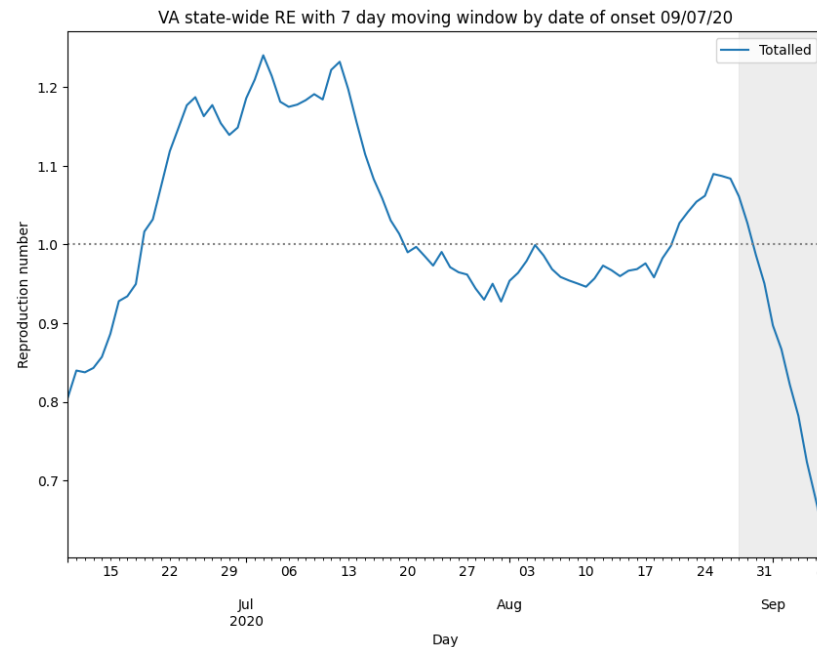
- Most states experiencing declines or plateaus in last weeks
- SC and NC showing some rebounds
- KY and WV plateauing, and TN declining but still quite high

- Good signs as test positivity shows recent decline in most states
- Testing volumes steady or growing in most states

Estimating Daily Reproductive Number

August 29th Estimates

Region	Current R_e	Diff Last Week
State-wide	1.027	0.023
Central	0.982	-0.005
Eastern	0.925	-0.004
Far SW	1.203	0.239
Near SW	1.073	-0.348
Northern	0.921	0.028
Northwest	1.649	0.538



Methodology

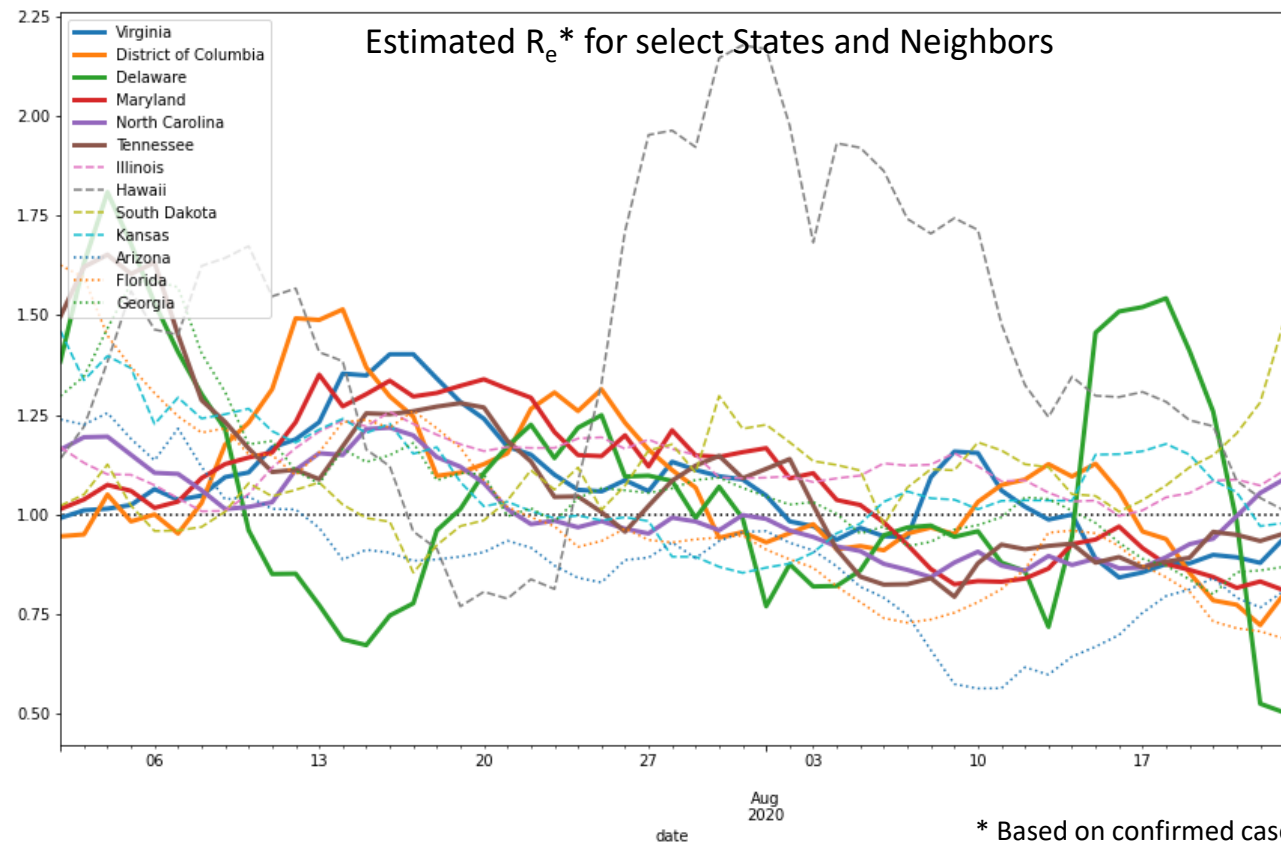
- Wallinga-Teunis method (EpiEstim¹) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, <https://doi.org/10.1093/aje/kwt133>

Other State Comparisons

Reproductive Number (R_e) has downward trend across hotspots and Virginia's neighbors

- New states in Midwest and Plains emerging as hot spots, IL, KS, SD as well as HI
- Virginia and neighboring states are mostly at and below 1



New states in Midwest and Plains emerging as hot spots

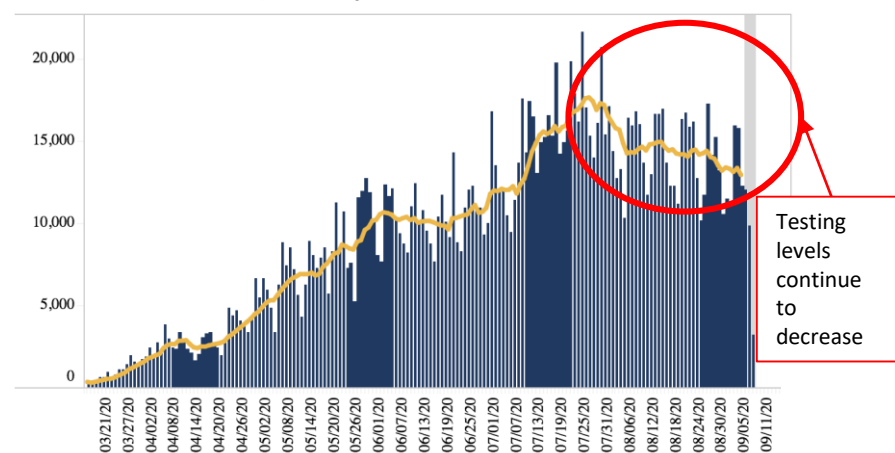
VA and neighbors continued decline

Changes in Case Detection

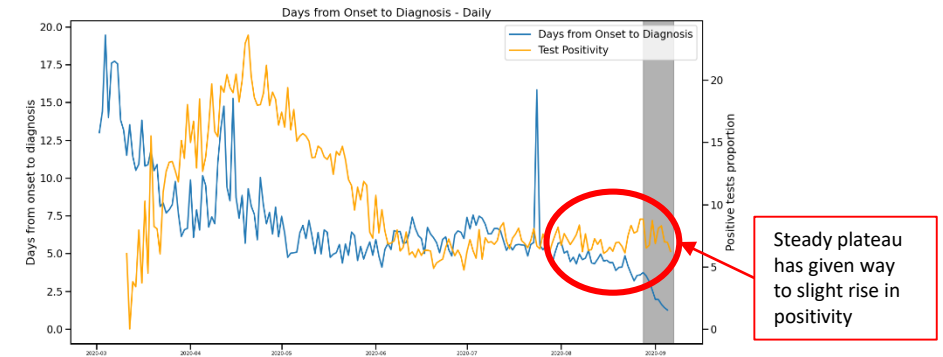
Timeframe (weeks)	Mean days	% difference from overall mean
April (13-16)	8.58	37.29%
May (17-21)	5.75	-7.97%
June (22-25)	5.84	-6.50%
July (26-30)	6.22	-0.39%
Aug (31-33)	4.55	-27.11%
Overall (13-33)	6.25	0%

Testing Encounters and test positivity have steadied and increased

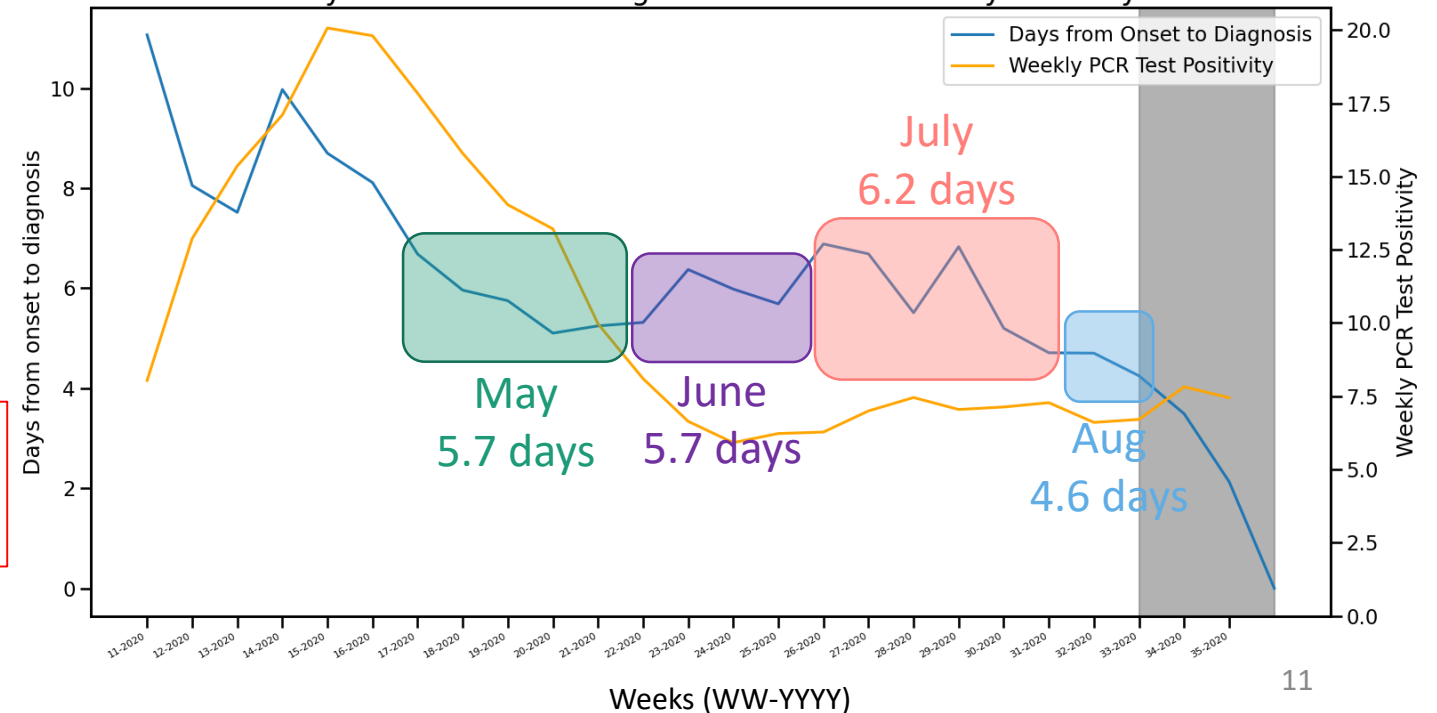
Number of Testing Encounters by Lab Report Date - All Health Districts, PCR Only



Test positivity vs. Onset to Diagnosis

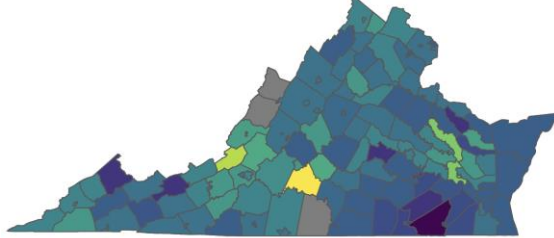


Days from Onset to Diagnosis and Test Positivity - Weekly

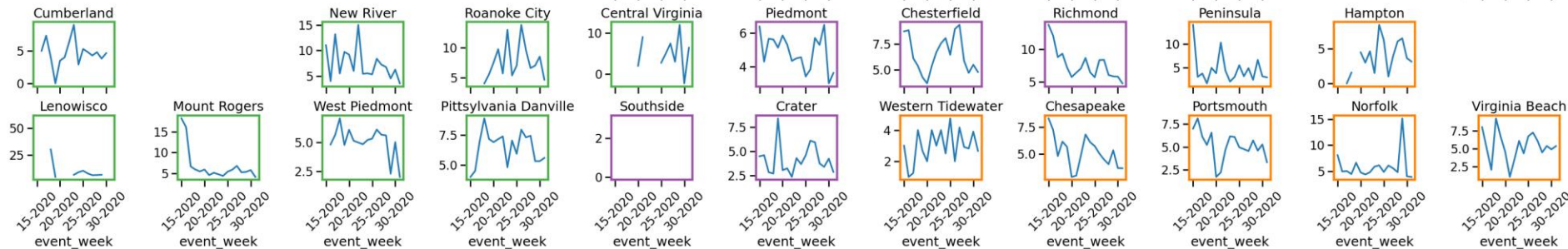


Changes in Case Detection – By District/Age

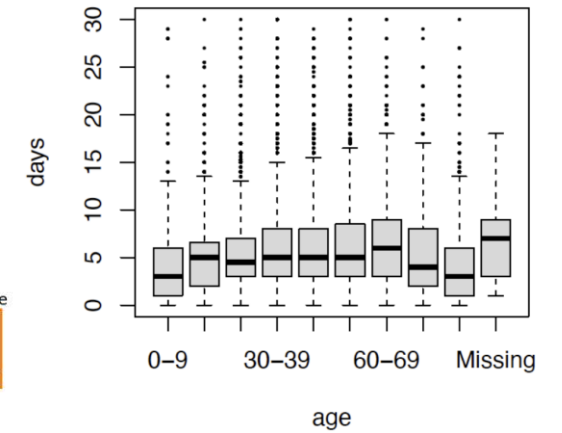
Median Days to Diagnosis
since March 1st



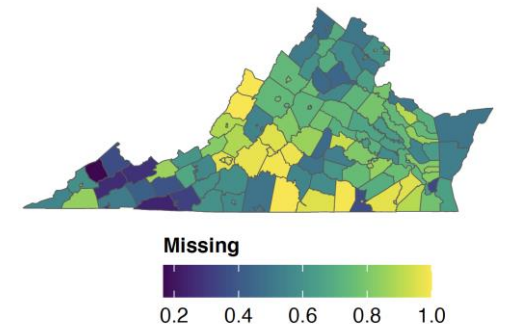
Days to Diagnosis
0.0 2.5 5.0 7.5 10.0 12.5



Slight variations by age group
(0-9, 70-79 and 80-89 have lower medians)
No significant variation by severity (hosp./ICU)
Delay by Age Group



Only ~35% records have entries
Days to Diagnosis Missing Rate

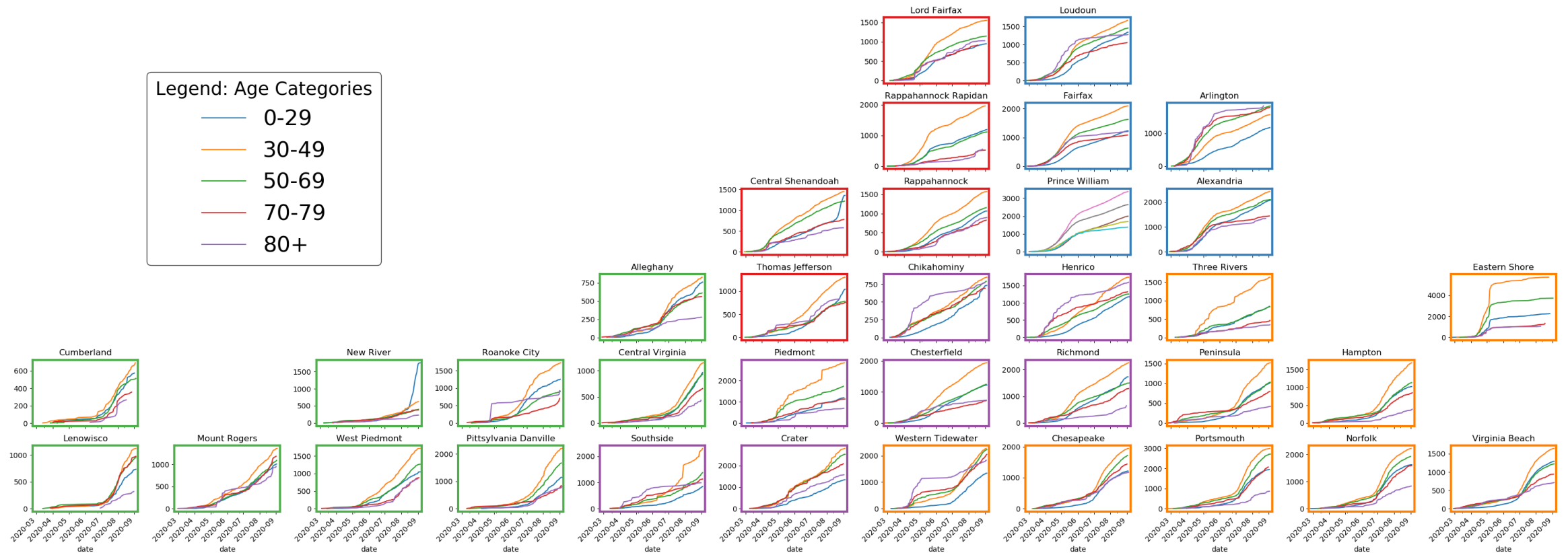


Age-Specific Attack Rates (per 100K)

Cumulative Age-specific Attack Rates (per 100k)

- Younger age groups outpace older in many districts

Age-adjusted Cumulative Prevalence Rate Per 100k District Population

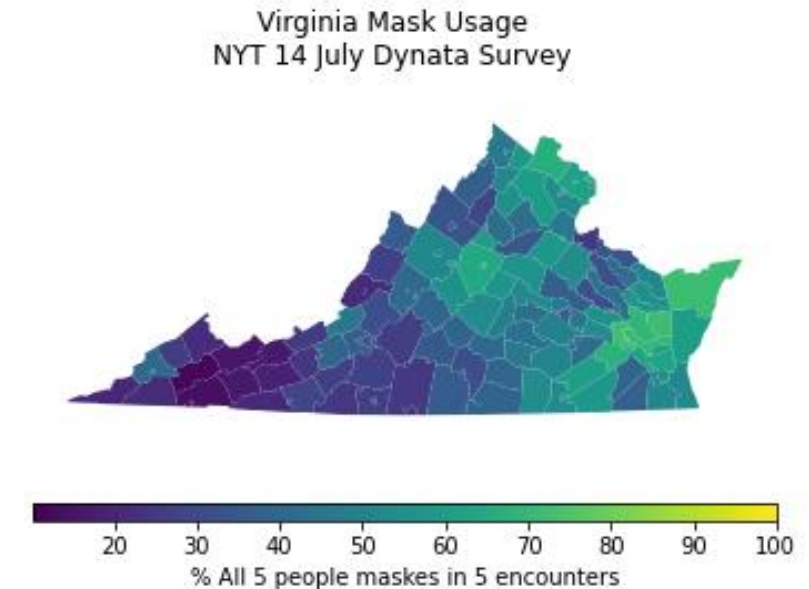
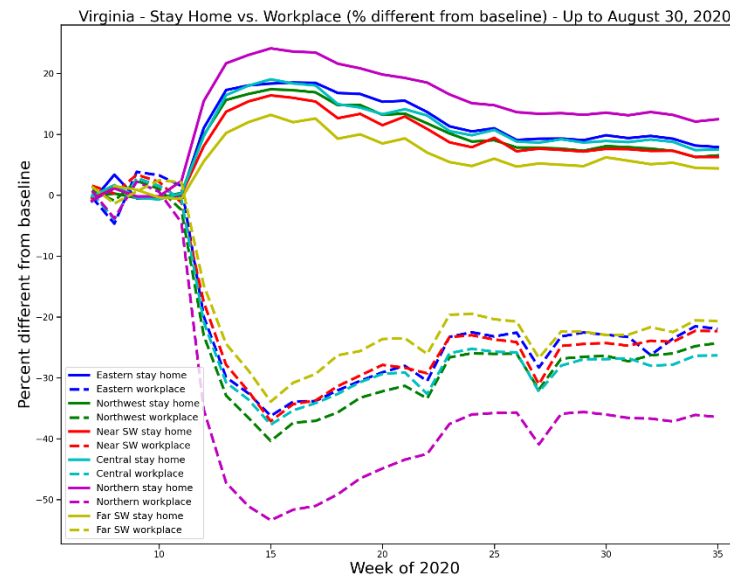
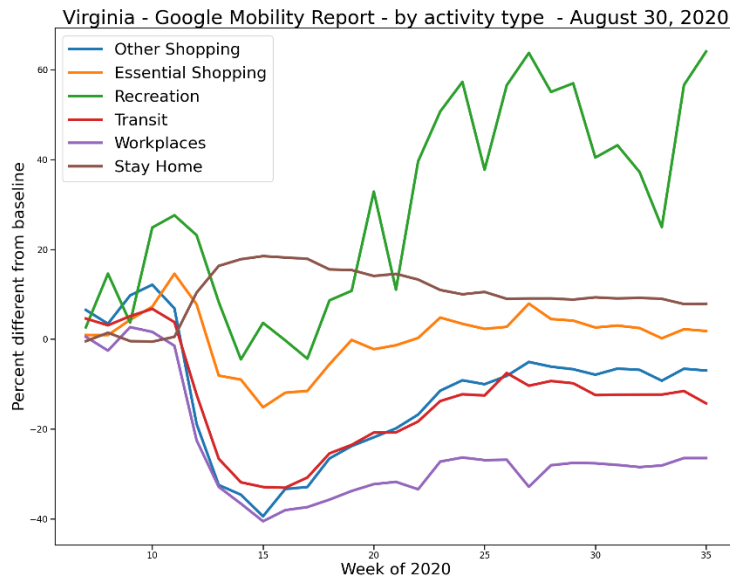


Estimating Effects of Social Distancing

Google Mobility data shows continued slow rebound (as of July 26th)

<https://www.google.com/covid19/mobility/>

- Continued slow reduction of those staying at home. Workplace levels remain low.
 - Urban/Rural variations in levels (e.g., Northern vs Far SW)
- Essential shopping back to baseline. Other shopping/transit trending towards baseline.
- Parks and recreation significantly higher than baseline (seasonal effects).
- Mask usage not evenly distributed, higher in Northern central, lower Southwest and Richmond area.



District Trajectories – New Surges starting

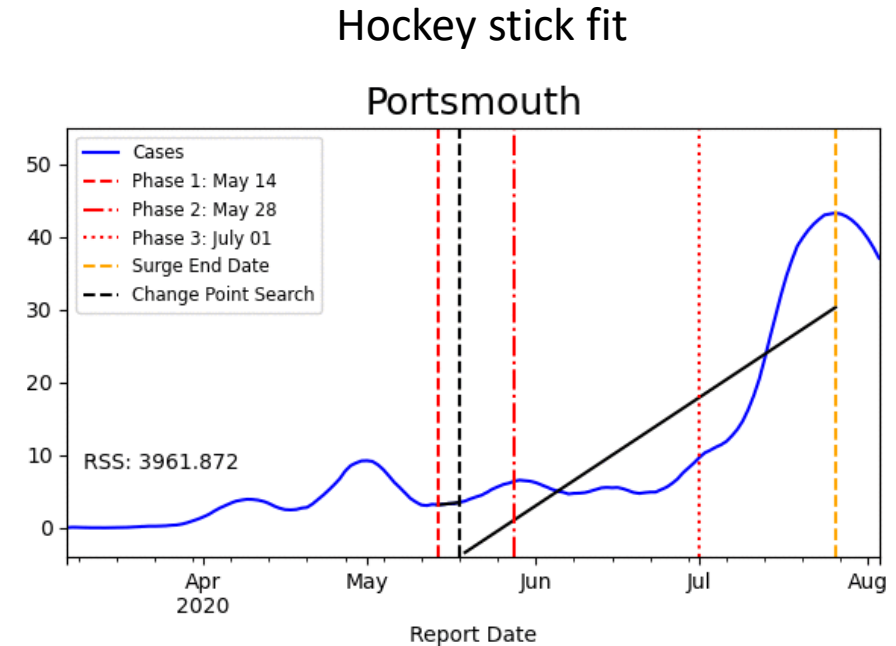
Hockey stick fit used to describe recent growth patterns

Declining: Sustained decreases following a recent peak

Plateau: Steady level with minimal trend up or down

Slow Growth: Sustained growth not rapid enough to be considered a Surge

In Surge: Currently experiencing sustained rapid growth and exceeds recent inflection points



Status	# Districts (last week)
Declining	13 (13)
Plateau	10 (12)
Slow Growth	10 (8)
In Surge	2 (2)

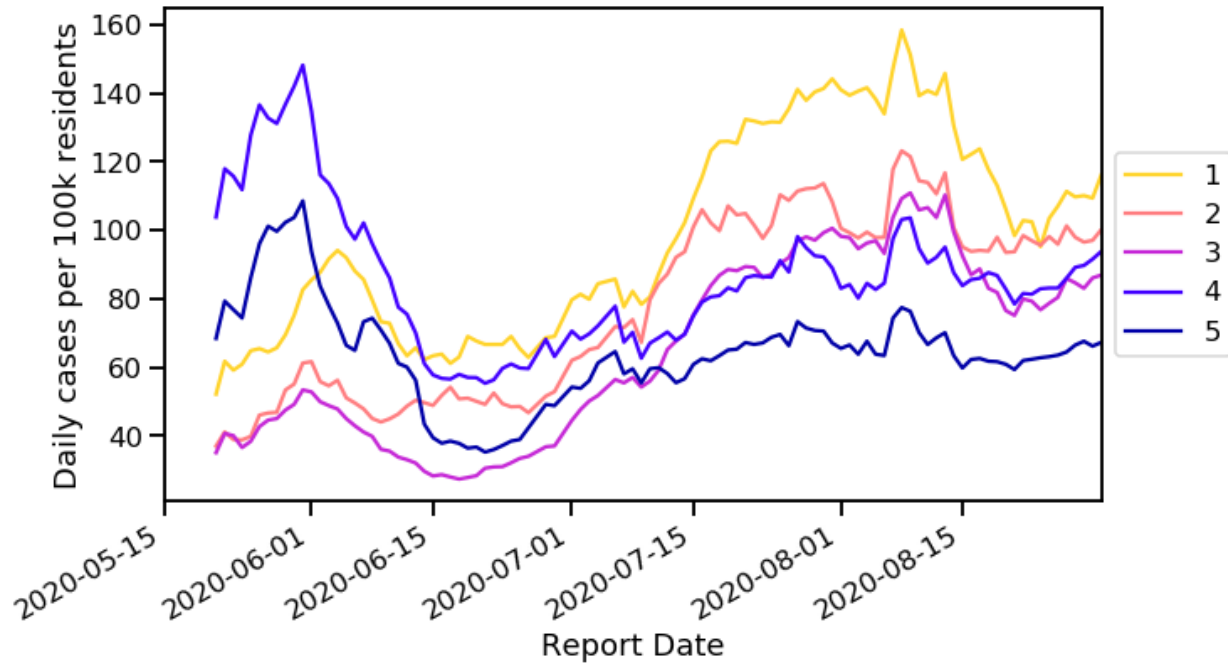
District Trajectories – New Surges starting

Status	# Districts (last week)
Declining	10 (13)
Plateau	13 (12)
Slow Growth	10 (8)
In Surge	2 (2)



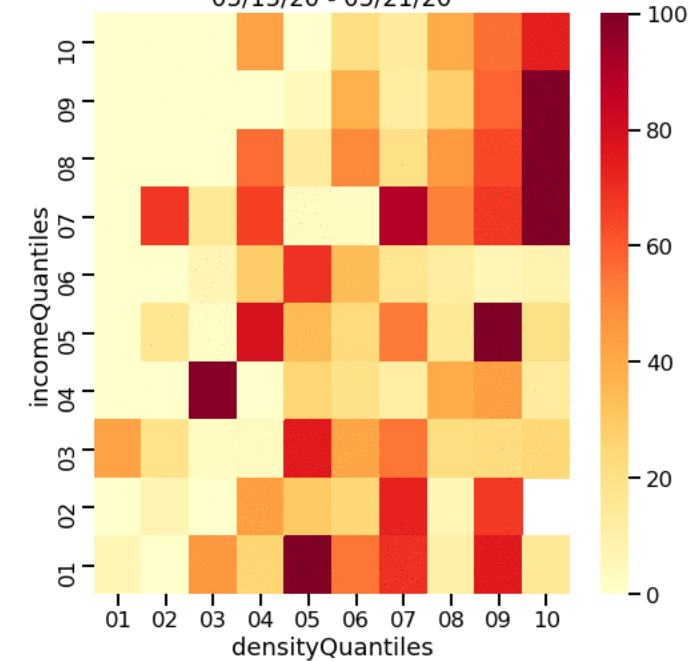
Impact across Density and Income

VDH 7-day moving average rate of new COVID-19 cases by zip code average household income (dollars/ household years) quantile



Lower 20% income zip codes still reporting highest case rates

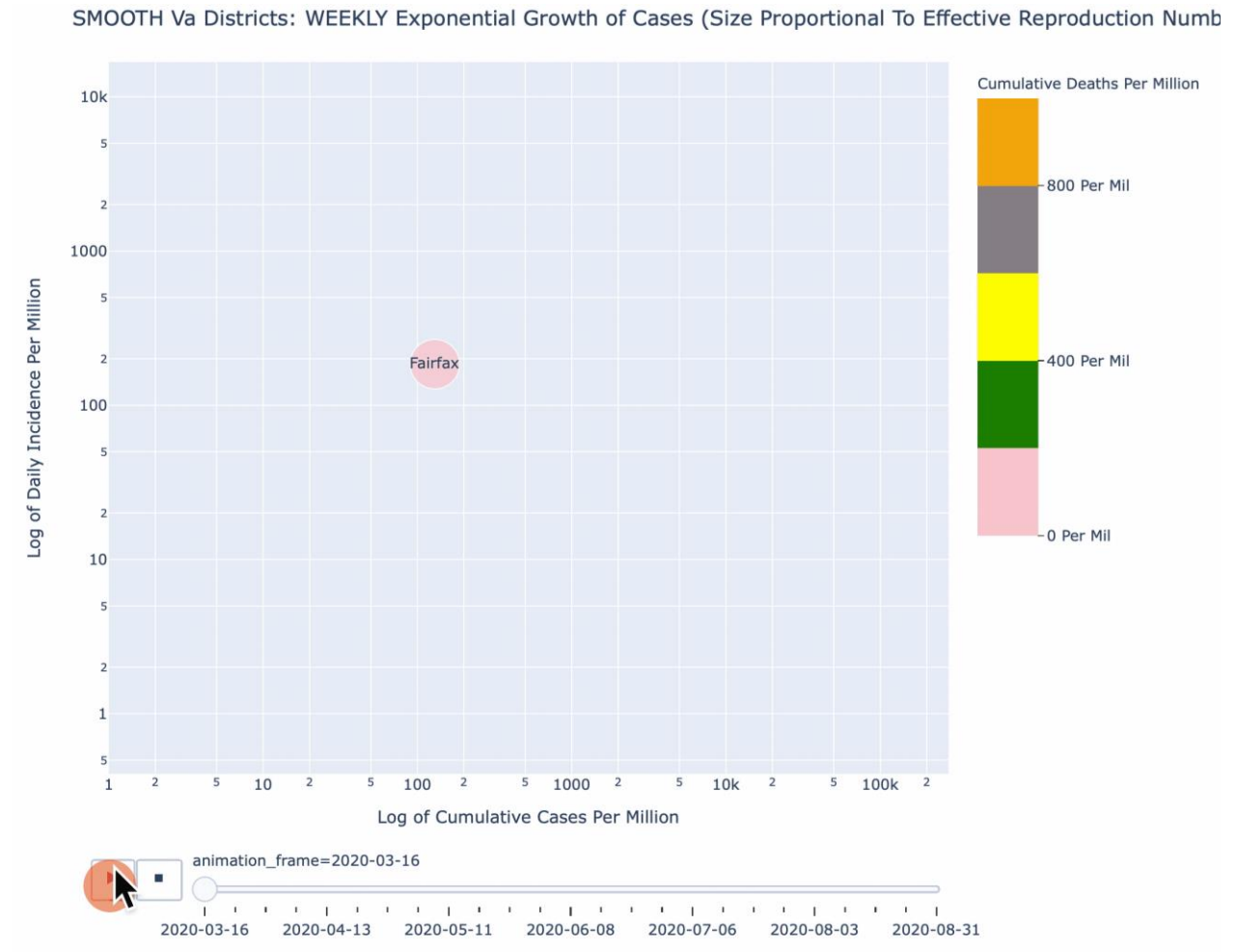
VDH mean cases per 100k by zip code population density (person/ sq mile) and average household income (dollars/ household years) quantiles
05/15/20 - 05/21/20



Can see the evolution from denser and wealthier zip codes to poorer and less dense zip codes

Evolution of Infections by District

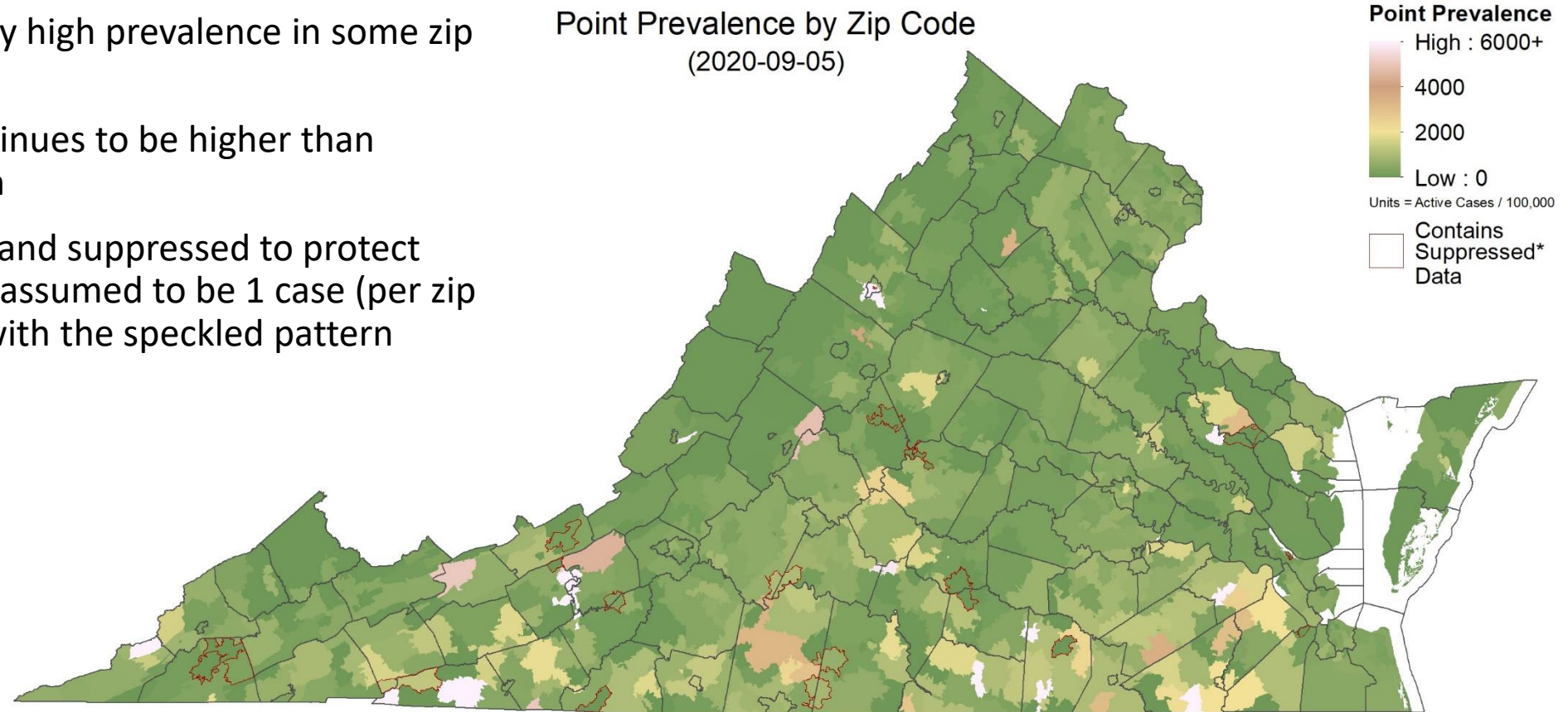
- From January to Present
- Cumulative cases vs. Daily Incidence
- Placed on log scale to minimize the differences between districts
- Colors represent cumulative deaths per million population
- Size changes based on daily estimated reproductive number



Zip code level weekly Case Rate (per 100K)

Case Rates in the last week by zip code

- Concentrations of very high prevalence in some zip codes
- Southern border continues to be higher than northern and western
- Many counts are low and suppressed to protect anonymity, those are assumed to be 1 case (per zip per day) and shown with the speckled pattern



Model Update – Adaptive Fitting

Adaptive Fitting Approach

Each county fit precisely, with recent trends used for future projection

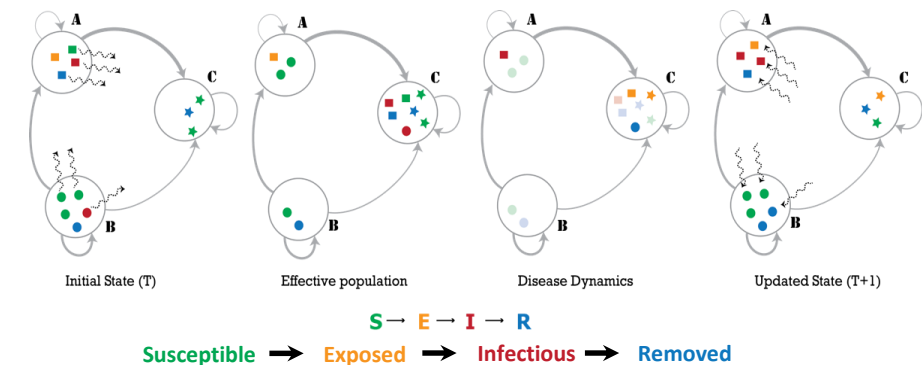
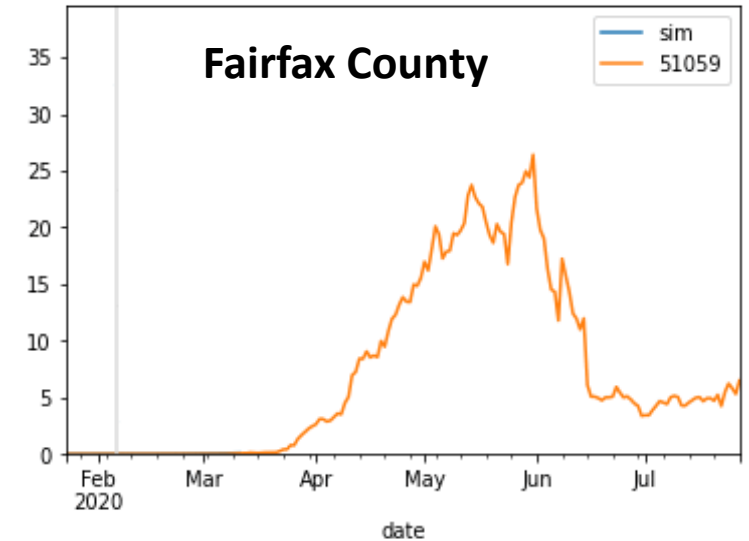
- Allows history to be precisely captured, and used to guide bounds on projections

Model: An alternative use of the same meta-population model, PatchSim

- Allows for future “what-if” Scenarios to be layered on top of calibrated model
- Eliminates connectivity between patches, to allow calibration to capture the increasingly unsynchronized epidemic

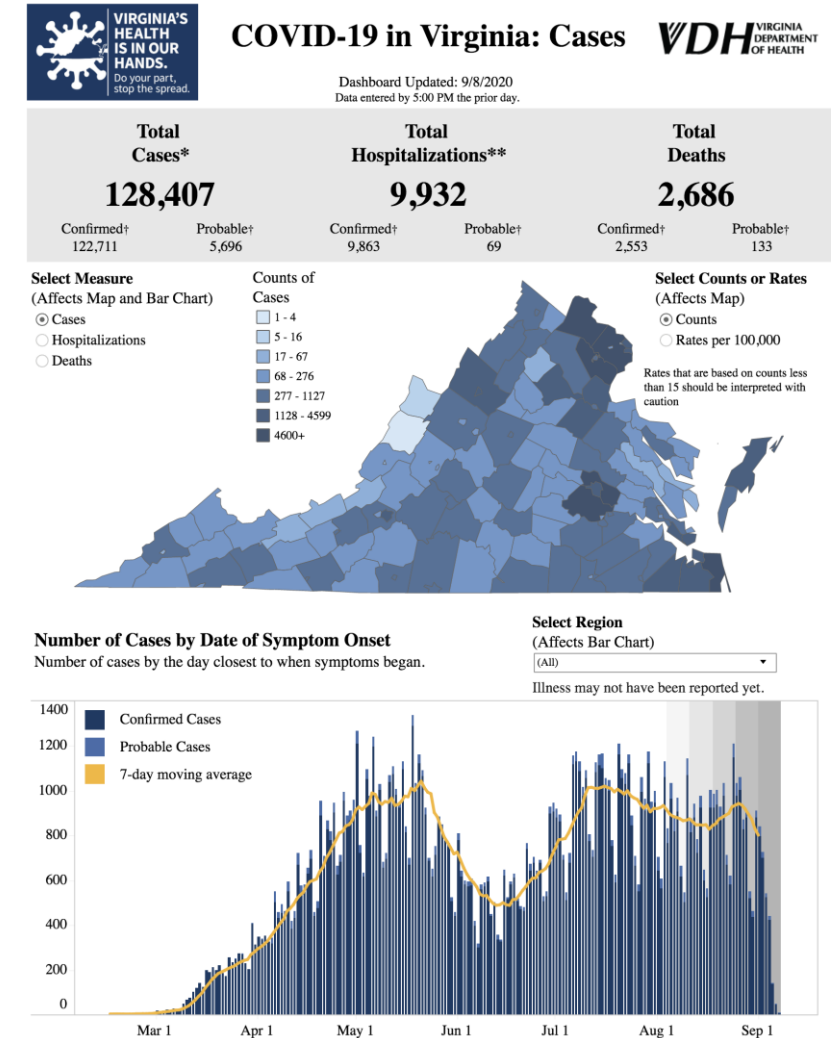
External Seeding: Steady low-level importation

- Widespread pandemic eliminates sensitivity to initial conditions
- Uses steady 1 case per 10M population per day external seeding



Calibration Approach

- **Data:**
 - County level case counts by date of onset (from VDH)
 - Confirmed cases for model fitting
- **Calibration:** fit model to observed data
 - Tune transmissibility across ranges of:
 - Duration of incubation (5-9 days), infectiousness (3-7 days)
 - Undocumented case rate (2x to 15x)
 - Detection delay: exposure to confirmation (4-12 days)
 - Approach captures uncertainty, but allows model to precisely track the full trajectory of the outbreak
- **Project:** future cases and outcomes using the most recent parameters with constraints learned from the history of the fit parameters
 - Mean trend from last 7 days used, adjusted by variances in the previous 3 weeks
 - 1 week interpolation to smooth transitions in rapidly changing trajectories
 - Particles with high error or variance filtered out



Accessed 10pm September 8, 2020
<https://www.vdh.virginia.gov/coronavirus/>

Scenarios – Seasonal Effects

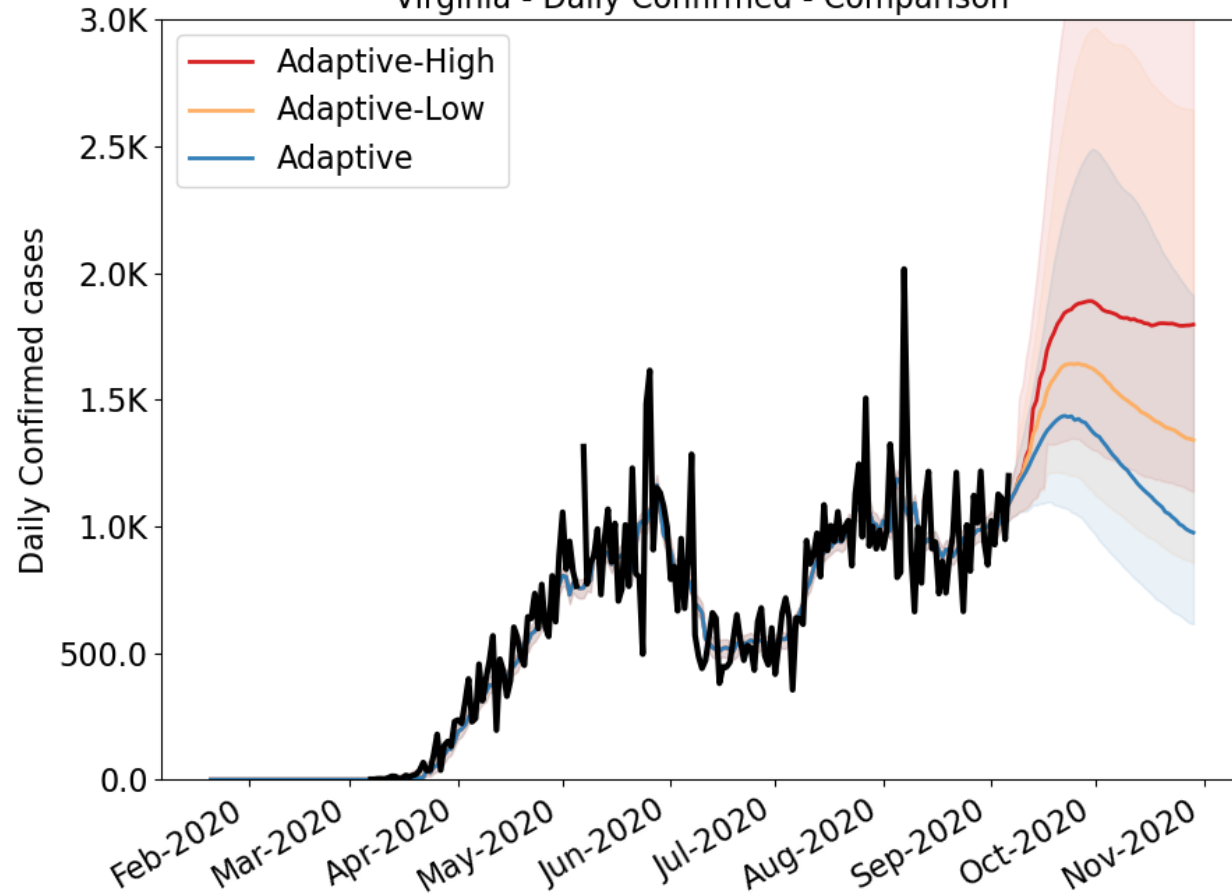
- Societal changes in the coming weeks may lead to an increase in transmission rates
 - Start of in-person school
 - Changes to workplace attendance
 - Seasonal impact of weather patterns
- Three scenarios provided to capture possible trajectories related to these changes starting following Labor Day, Sept 7th, 2020
 - Adaptive: No change from base projection
 - Adaptive-Low: 10% increase in transmission starting Sept 8th, 2020
 - Adaptive-High: 20% increase in transmission starting Sept 8th, 2020

Model Results

Outcome Projections

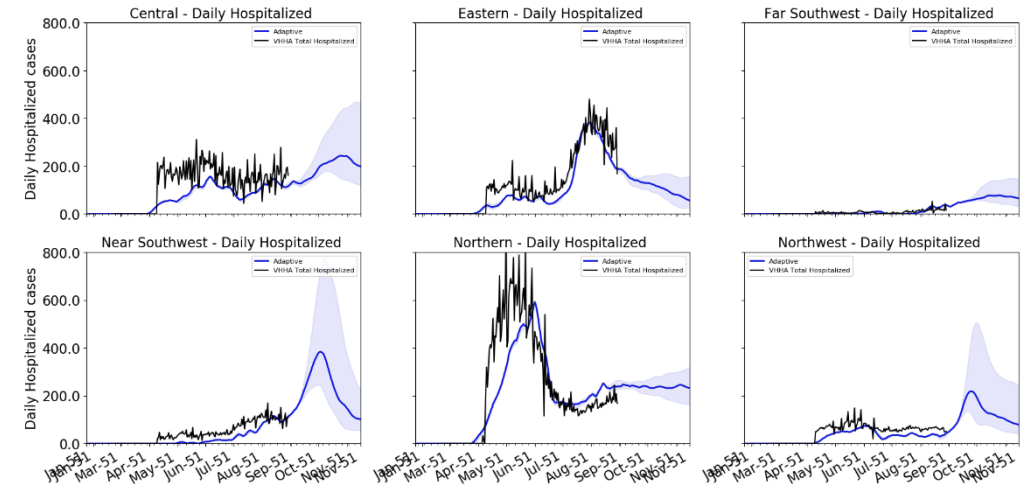
Confirmed cases

Virginia - Daily Confirmed - Comparison

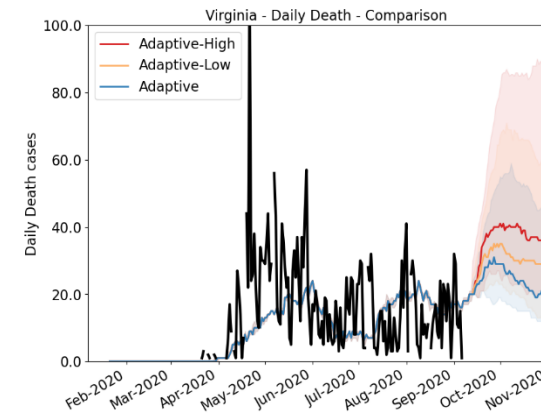


Estimated Hospital Occupancy

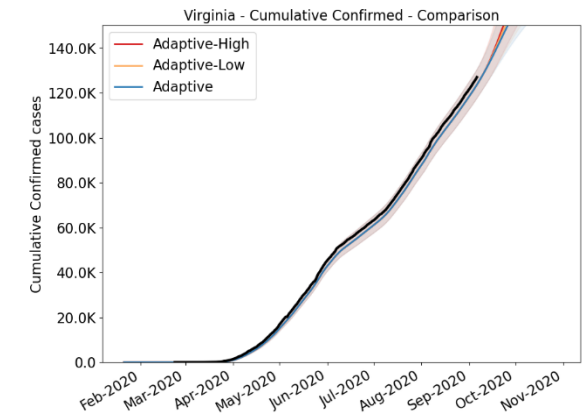
Virginia: Daily Total Confirmed Hospitalized Versus Sim - 8 Day Rolling



Daily Deaths



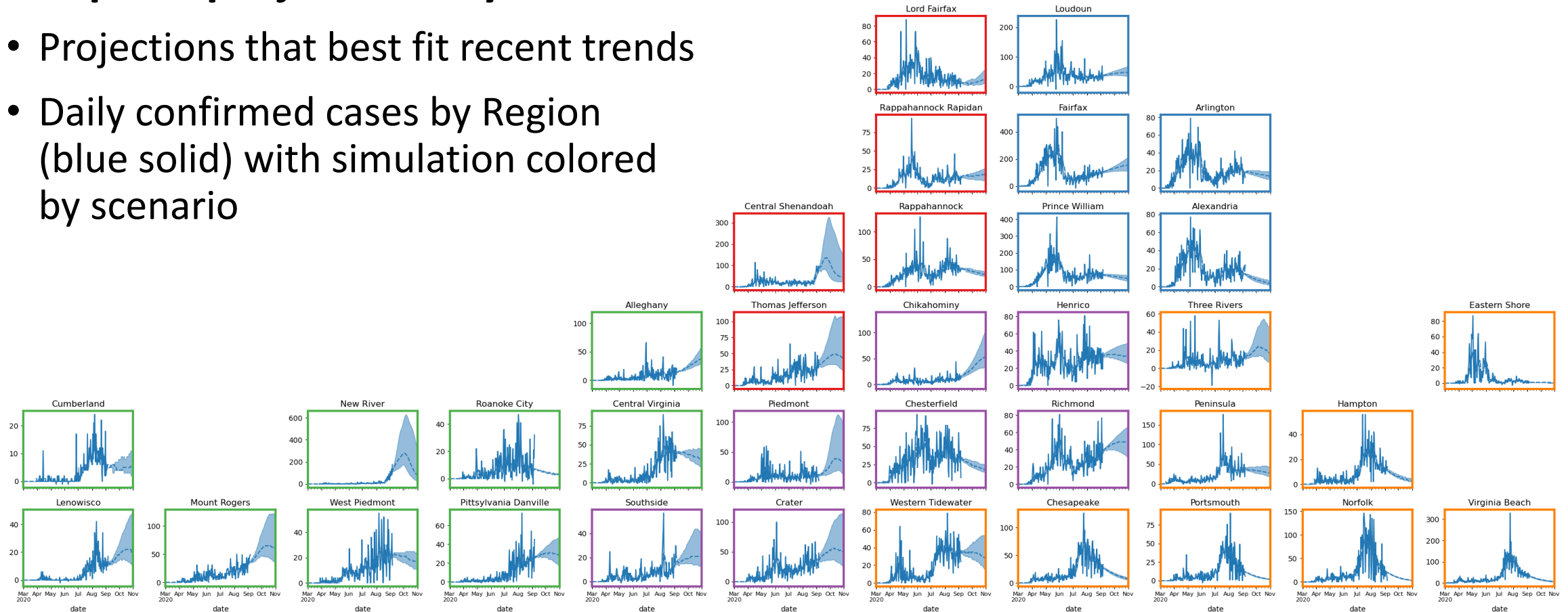
Cumulative Confirmed cases



District Level Projections: Adaptive

Adaptive projections by District

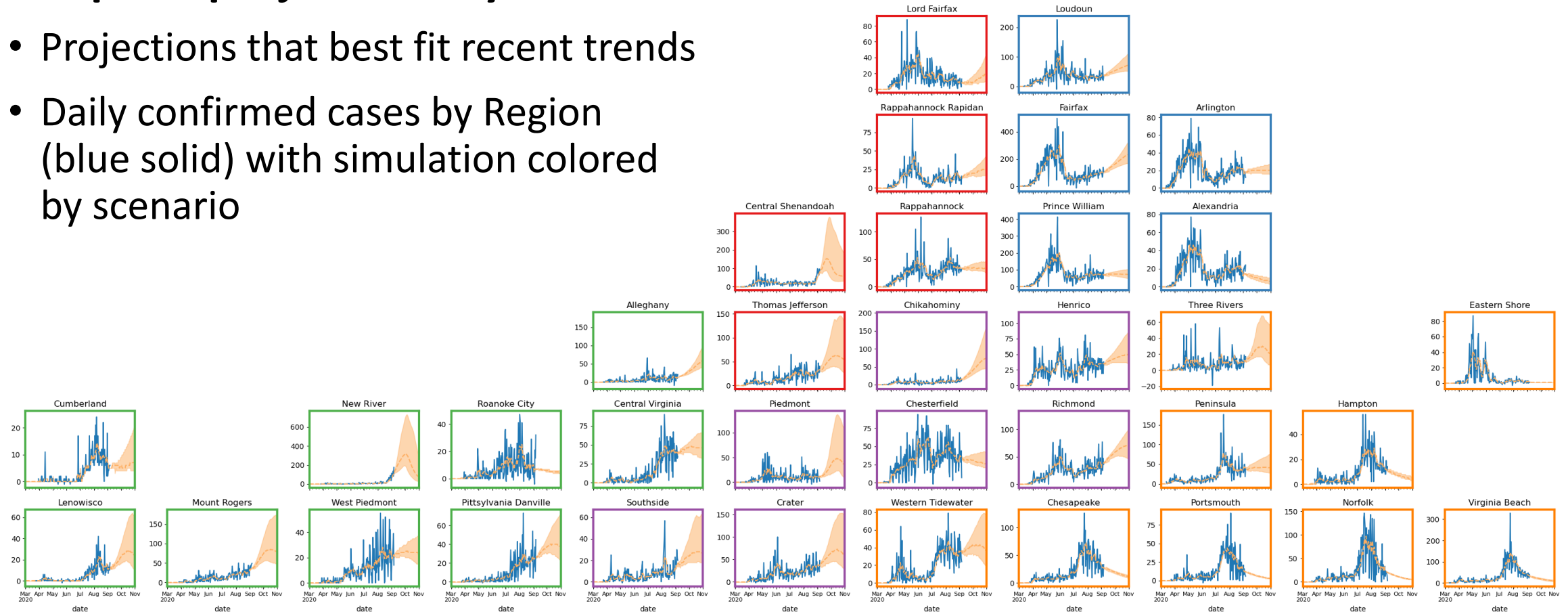
- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation colored by scenario



District Level Projections: Adaptive-Low

Adaptive projections by District

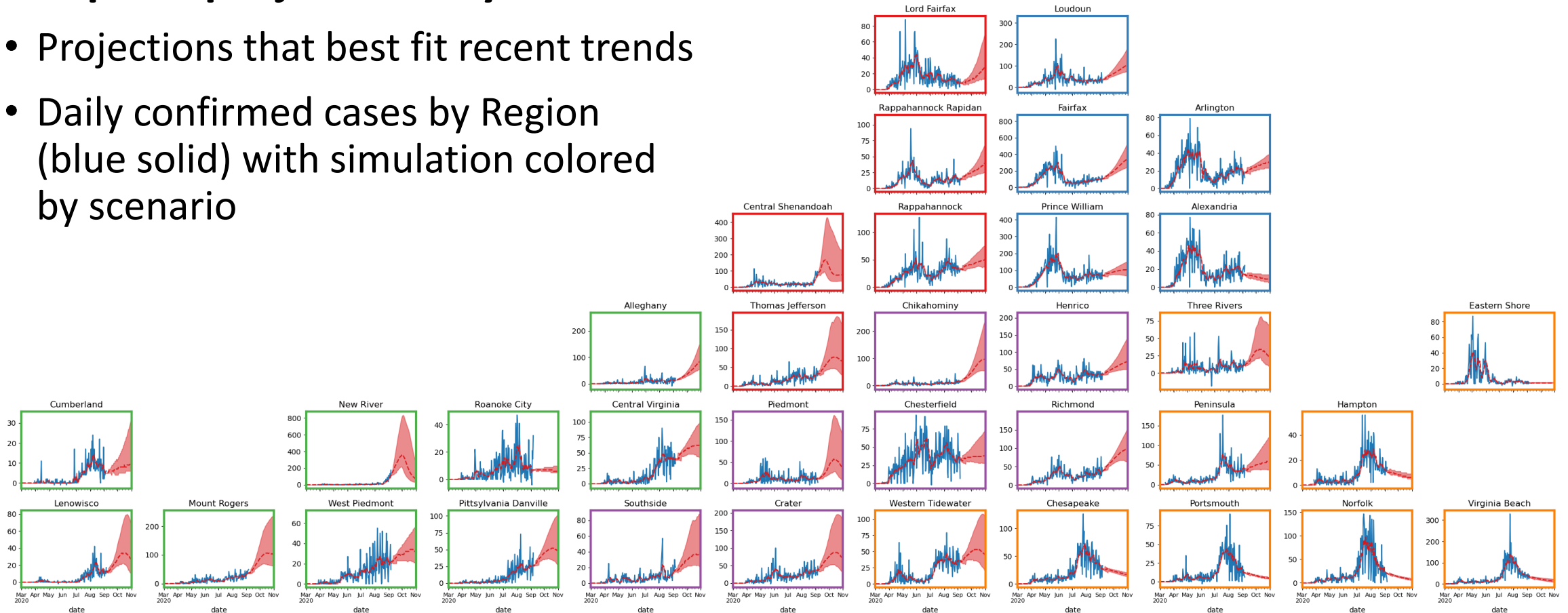
- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation colored by scenario



District Level Projections: Adaptive-High

Adaptive projections by District

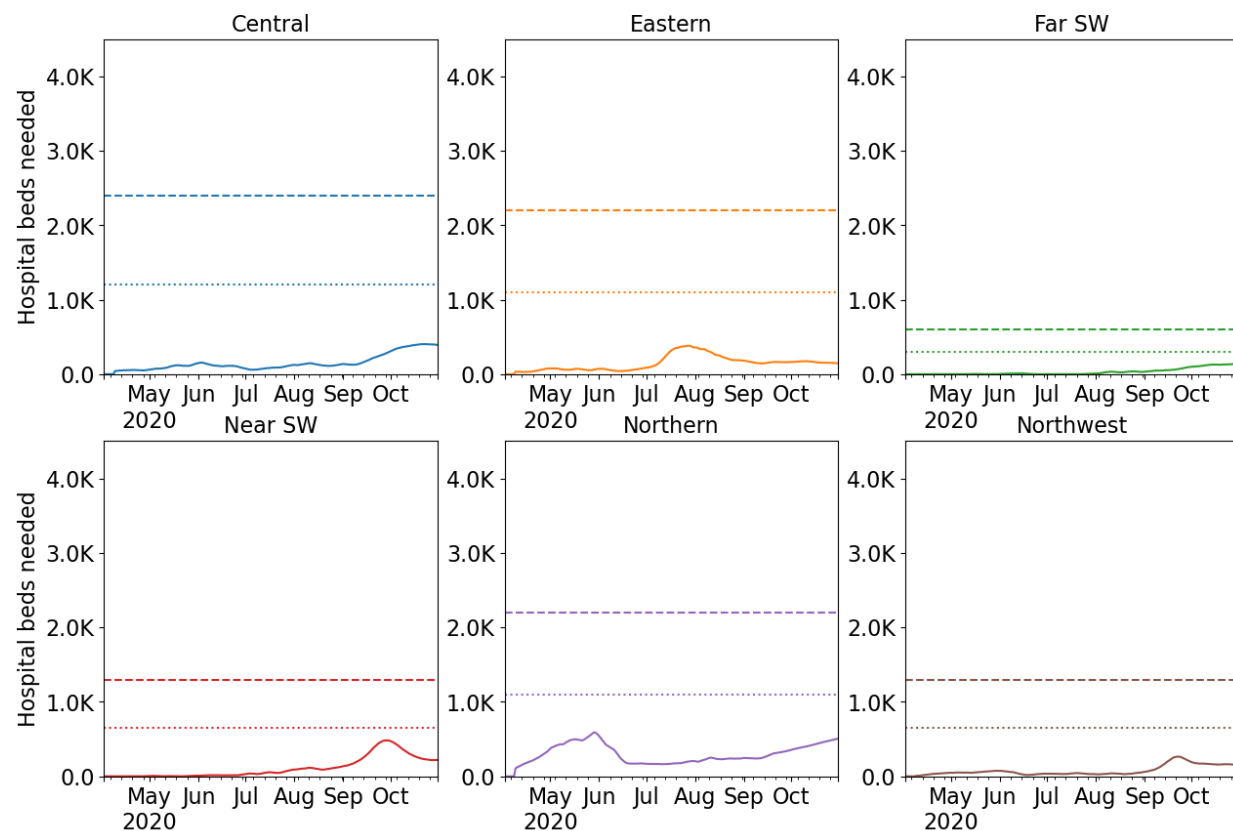
- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation colored by scenario



Hospital Demand and Capacity by Region

Capacities by Region – Adaptive-High

COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds



Week Ending	Adaptive	Adaptive-High
9/6/20	7,010	7,010
9/13/20	7,982	8,080
9/20/20	9,270	10,896
9/27/20	9,980	12,797
10/4/20	9,724	13,170
10/11/20	8,973	12,868
10/18/20	8,199	12,674
10/25/20	7,520	12,588
11/1/20	6,938	12,547
11/8/20	6,478	12,450
11/15/20	6,073	12,241
11/22/20	5,670	11,850

Based on Adaptive-High scenario

- No regions forecast to exceed capacity

* Assumes average length of stay of 8 days

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.

Even without perfect projections, we can confidently draw conclusions:

- **Mixed trends remain, with strong surges in several districts.**
- Incidence hovers at national average, which is higher this week ~13/100K.
- Projections are also mixed across a range of slow-growth, plateaus, and declines.
- Recent updates:
 - Adaptive Fitting projection remains, slight adjustments to projection filtering.
 - Trajectory descriptions more fully developed.
- The situation is changing rapidly. Models will be updated regularly.

References

Venkatramanan, S., et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS computational biology* 15.9 (2019): e1007111.

Arindam Fadikar, Dave Higdon, Jiangzhuo Chen, Bryan Lewis, Srinivasan Venkatramanan, and Madhav Marathe. Calibrating a stochastic, agent-based model using quantile-based emulation. *SIAM/ASA Journal on Uncertainty Quantification*, 6(4):1685–1706, 2018.

Adiga, Aniruddha, Srinivasan Venkatramanan, Akhil Peddireddy, et al. "Evaluating the impact of international airline suspensions on COVID-19 direct importation risk." *medRxiv* (2020)

NSSAC. PatchSim: Code for simulating the metapopulation SEIR model. <https://github.com/NSSAC/PatchSim> (Accessed on 04/10/2020).

Virginia Department of Health. COVID-19 in Virginia. <http://www.vdh.virginia.gov/coronavirus/> (Accessed on 04/10/2020)

Biocomplexity Institute. COVID-19 Surveillance Dashboard. <https://nssac.bii.virginia.edu/covid-19/dashboard/>

Google. COVID-19 community mobility reports. <https://www.google.com/covid19/mobility/>

Cuebiq: COVID-19 Mobility insights. <https://www.cuebiq.com/visitation-insights-covid19/>

Biocomplexity page for data and other resources related to COVID-19: <https://covid19.biocomplexity.virginia.edu/>

Questions?

Points of Contact

Bryan Lewis
brylew@virginia.edu

Srini Venkatramanan
srini@virginia.edu

Madhav Marathe
marathe@virginia.edu

Chris Barrett
ChrisBarrett@virginia.edu

Biocomplexity COVID-19 Response Team

Aniruddha Adiga, Abhijin Adiga, Hannah Baek, Chris Barrett, Golda Barrow, Richard Beckman, Parantapa Bhattacharya, Andrei Bura, Jiangzhuo Chen, Patrick Corbett, Clark Cucinell, Allan Dickerman, Stephen Eubank, Arindam Fadikar, Joshua Goldstein, Stefan Hoops, Sallie Keller, Ron Kenyon, Brian Klahn, Gizem Korkmaz, Vicki Lancaster, Bryan Lewis, Dustin Machi, Chunhong Mao, Achla Marathe, Madhav Marathe, Fanchao Meng, Henning Mortveit, Mark Orr, Przemyslaw Porebski, SS Ravi, Erin Raymond, Jose Bayoan Santiago Calderon, James Schlitt, Aaron Schroeder, Stephanie Shipp, Samarth Swarup, Alex Telionis, Srinivasan Venkatramanan, Anil Vullikanti, James Walke, Amanda Wilson, Dawen Xie

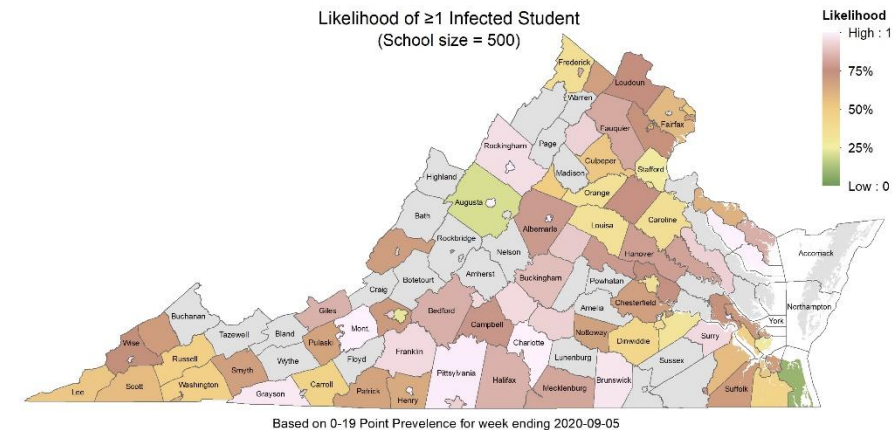
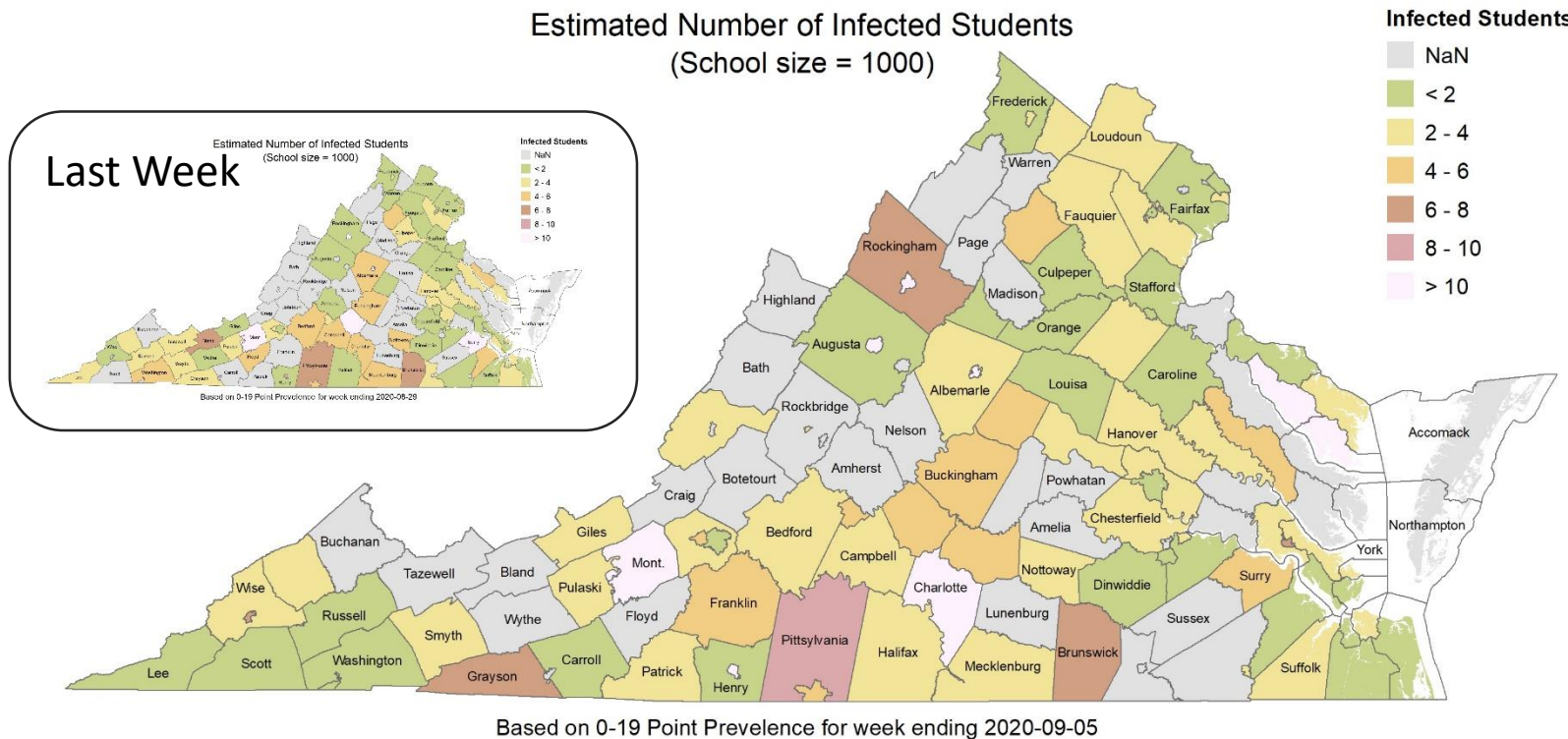


Supplemental Slides

School Age Prevalence

If all schools were open this past week, how many infected students might we expect to be in attendance?

- Based on prevalence during week of August 30 – Sept 5th
- Using school-age incidence in the last week, we estimate the likelihood any collection of school age kids in a school size of 500 will have at least one infection
- Assume that for each confirmed case there are 6 other undetected infections



Recent Parameter Validation

New York State [announced sero-prevalence survey results](#) on May 2nd

- 15,000 antibody tests conducted randomly through the state at grocery stores
- **Total Attack Rate:** 12.3%

Estimation of undetected infections

- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

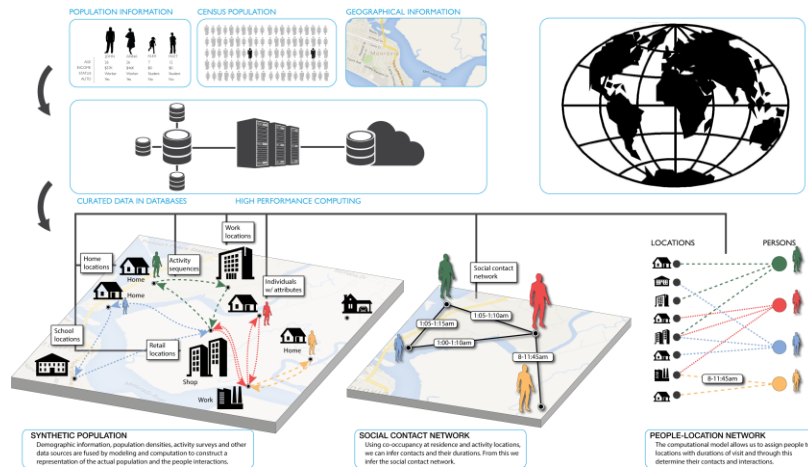
Estimation of hospitalizations from infections

- Total infections in NY = 2.46M, total of 66K hospitalizations
- Hospitalizations = 2.7% of infections (close to 2.25% used in model)

Agent-based Model (ABM)

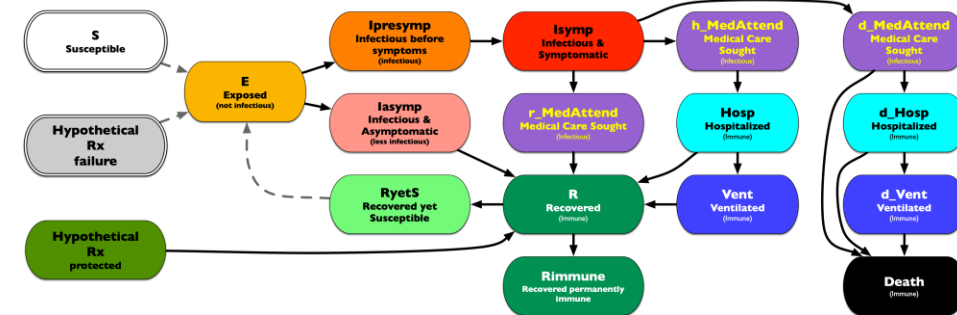
EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing



Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations



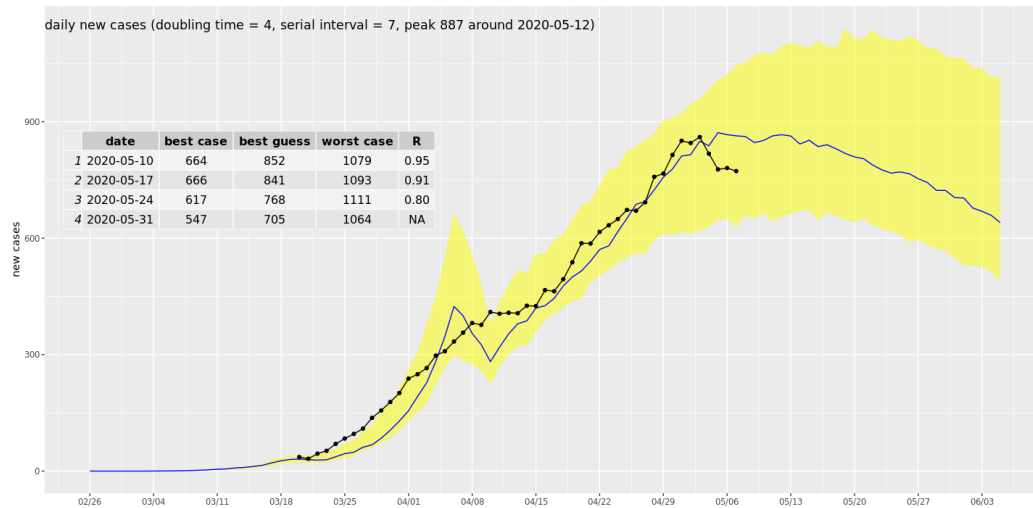
Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

ABM Social Distancing Rebound Study Design

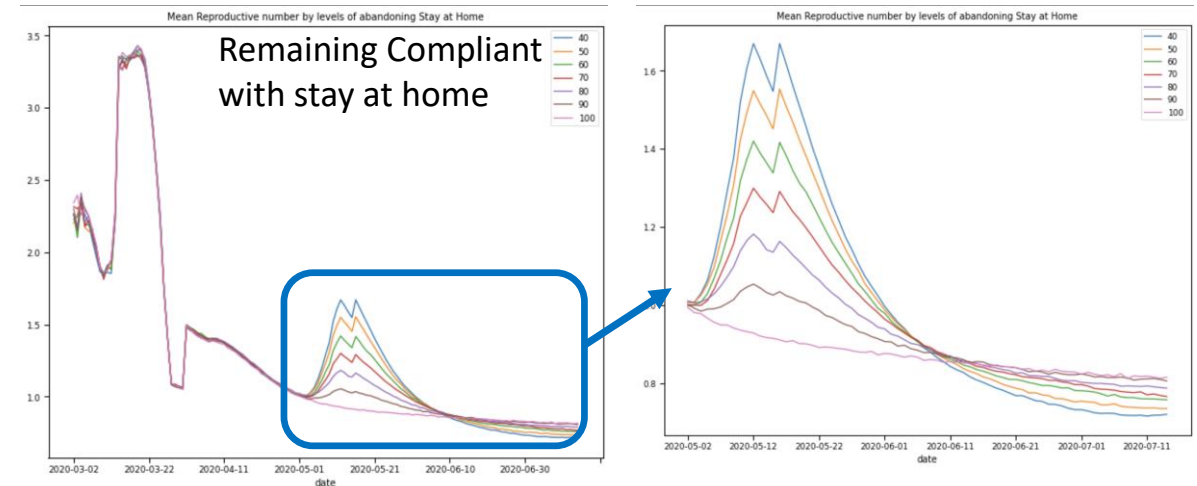
Study of "Stay Home" policy adherence

- Calibration to current state in epidemic
- Implement "release" of different proportions of people from "staying at home"



Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim



Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a $1/6^{\text{th}}$ return to pre-pandemic levels

Medical Resource Demand Dashboard

<https://nssac.bii.virginia.edu/covid-19/vmrddash/>

